ATTACHMENT 1

Potential Interference to GPS from UWB Transmitters

Test Results

Phase 1A:

Accuracy and Loss-of-Lock Testing
for Aviation Receivers

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1.0 Background

The Global Positioning System (GPS) is fundamental to the critical infrastructure of the United States (US) and international community. GPS is a fully operational service that provides a global source for accurate timing and positioning, 24 hours a day. GPS is presently used by aviation for the en-route and non-precision landing phases of flight. GPS is currently used within the US for precision approach and landings and is in the final stages of approval as a national and international standard. Companion GPS-based applications for runway incursion and ground traffic management are also underway. In additional GPS-based public safety systems and services are being deployed. Planned or proposed systems, such as Enhanced 911 (E-911) and personal location and medical tracking devices are soon to be commercially available. Additional future systems are planned for land, marine and space applications. The US telecommunications and power distribution systems are dependent upon GPS for network synchronization timing. Further, GPS is a powerful enabling technology that has created new industries and new industrial practices fully dependent upon GPS signal availability and continuity. Several critical industries, both aviation and non-aviation, would incur adverse impact if there were degradation to GPS signal continuity and availability.

Ultra-Wideband (UWB) technology is based on very short pulses of radio frequency energy. Its wide signal bandwidth offers benefits such as excellent multipath immunity. UWB technology has potential in a variety of applications including communication and ranging, and is expected to see increased civil use in the future. UWB technology is the focus of the Notice of Inquiry (NOI) of the Federal Communications Commission (FCC) under the Office of Engineering and Technology (OET) entitled "Notice of Inquiry in the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems", FCC Docket Number (No.) 98-208/ET No. 98-153.

Since GPS has such a pivotal role in so many critical systems that the public depends upon for its safety and well being, it is necessary to determine the potential for interference from UWB systems to GPS. Preliminary analysis and testing have indicated a likely interference impact to GPS reception from some types of UWB sources. This suggests a threat to aviation receivers that have already been fielded and are relied upon to protect user safety to hazardous risk levels of 10^{-7} or lower per operation. These preliminary findings motivated the development of a plan for controlled testing to determine the nature and extent of the potential for interference to GPS from a broad range of UWB signals in order to assure public safety and safety-of-life. Without test results, such an assurance cannot be made with full confidence.

The aviation community has a large body of developed and published technical standards for GPS and defined interference criteria making it logical to initiate the first phase of testing for aviation receivers based on this background. This test phase uses two primary metrics: pseudorange accuracy and signal loss-of-lock threshold. Aviation receivers meeting published specifications are used to measure accuracy and to observe loss-of-lock. A GPS simulator provides the GPS signal input for a single satellite, and the UWB parameters are provided by a prototype UWB waveform generator where the various UWB waveform parameters can be varied independently in a controlled manner. These metrics were considered appropriate for the first phase of testing and results are contained within this report. A second phase of testing, which has been initiated but is not complete at the time of this report, focuses on examining the impact on non-aviation receivers. For this second phase of receiver testing, commercial land receivers will be used to measure reacquisition time after a satellite signal is lost.

The first phase of the test program concentrates on the aeronautical applications of GPS L1 signal, centered at 1575.42 MHz. These tests are necessary to evaluate the impact that UWB device emissions could have on safety-of-life aeronautical systems that are based on the GPS Standard Positioning Service (SPS), the Wide Area Augmentation System (WAAS), and the Local Area Augmentation System (LAAS). Allowable levels of interference are already specified in the LAAS Minimum Performance Standards (MASPS) and the WAAS and LAAS Minimum Operating Performance Standards (MOPS) interference "masks". Appropriate documents are included as references [1-8]

The impact of UWB on the aeronautical and non-aeronautical use of GPS depends on the specific operational scenarios envisioned, which will define the number of UWB transmitters and proximity of these transmitters to GPS users. The results of the UWB testing conducted by Stanford are intended to be used to evaluate the harm to GPS in each of these scenarios. The test approach described in the next section supports this by determining the impact of a single UWB transmitter relative to the impact of a single broadband noise transmitter. Measuring the effect of individual UWB transmitters in terms of broadband interferers allows standard link-budget techniques to be used to determine the impact on GPS users. Of course, our data can only support the analysis of the impact of one UWB source on a GPS receiver. The impact of multiple UWB emitters cannot be predicted based on our results. In addition, our data does not address the deleterious effect of UWB signals with such high peak power that they excite non-linear effects in the GPS receiver.

2.0 Introduction: Test Philosophy and Scope

The goal of this initial phase of UWB testing is to characterize the interference effects of UWB emissions on a typical aviation GPS receiver in a controlled test environment. Some UWB emissions may be well described as noise-like, while others may have discrete spectral lines in the vicinity of the GPS L1 frequency. An RFI-equivalence concept was developed to relate the interference impact of UWB signals on GPS over a range of UWB emission parameters to that of a known and well-understood RFI source, i.e., broadband "white" noise. The term "broadband" or "white noise" is used to characterize a flat frequency spectrum across a particular region of interest. That particular region of interest in this case is the GPS L1 band. The approach used in this test plan is to determine the UWB interference impact for a given UWB transmission relative to a known level of broadband noise. This relative comparison is conducted in the area about the point where the GPS receiver meets its performance criterion. This allows a normalization of receivers and provides relative performance. Relative performance is critical as it would be unfair to utilize a GPS receiver for testing with performance significantly better than the minimal required. Likewise, it would also be biased to conduct a test with a receiver that does not meet the minimum performance requirements.

Pseudorange (PR) measurement accuracy (and the related integrity, or safety, of GPS positioning), acquisition and reacquisition times, and loss-of-tracking thresholds are the four important performance metrics to GPS users. Pseudorange accuracy, or the accuracy on the relative distance between the satellite and receiver, was chosen to be the primary test criterion for aviation receiver testing. Pseudorange measurement accuracy is influenced by degradations in both code-delay and carrier-phase tracking. As such, it is a sensitive metric for the aviation applications. The most demanding precision approach operations require a pseudorange measurement standard deviation of less than 15 cm [2,3]. The equivalence concept test methodology consists of inserting broadband noise into the GPS receiver and increasing its level until 15 cm of pseudorange error standard deviation is measured. The broadband noise source is then reduced by 4 dB and the UWB source is added into the channel. The broadband noise power remains fixed at the 4 dB back-off point and the UWB emission level is increased until a measure of 15 cm pseudorange error standard deviation is observed. The total power from both the broadband noise and UWB emitter is measured as UWB power is increased in order to obtain the equivalence. Upon completion of the testing, another UWB parameter (e.g. Pulse Repetition Frequency (PRF)) is then chosen, and the entire sequence repeated until all combinations of UWB parameters have been investigated.

This process is depicted in Figure 1 where one curve represents what would be expected from broadband noise and then two traces from UWB parameter set i and j indicate UWB results which would be worse and better than, respectively, the broadband noise measurement. There are a multitude of UWB parameters that need to be considered, many more than the two depicted by i and j in this hypothetical example. However, it should be possible to use the test data to quantify the impact of all possible UWB parameters individually on GPS relative to broadband noise by generating additional curves based on each UWB parameter. From this interference effect data, a profile of the various UWB waveforms can be drawn relative to white noise and will also indicate those UWB parameters that have the most significant effect on GPS accuracy performance.

A simple analogy to this equivalence test can be developed using a volume-to-mass experiment designed to find the density of a new liquid by empirical means. Imagine a bucket with 1 liter of water of known density sitting on a scale so that its mass (and thus its density) is observable. A specific volume of water, say 250 ml, is removed from the bucket, and "UWB liquid" of unknown density is poured in until the bucket is at the 1 liter mark again. The amount of UWB liquid added (assuming no chemical reaction) must be 250 ml. Observing the mass of the bucket after adding UWB liquid tells us whether UWB liquid is denser than water (the mass of the bucket after refilling with UWB liquid is greater than the mass of the bucket before water was removed), less dense than water (the mass after refilling is lower than the mass before water was removed), or has about the same density as water (the mass after refilling matches the mass before water was removed).

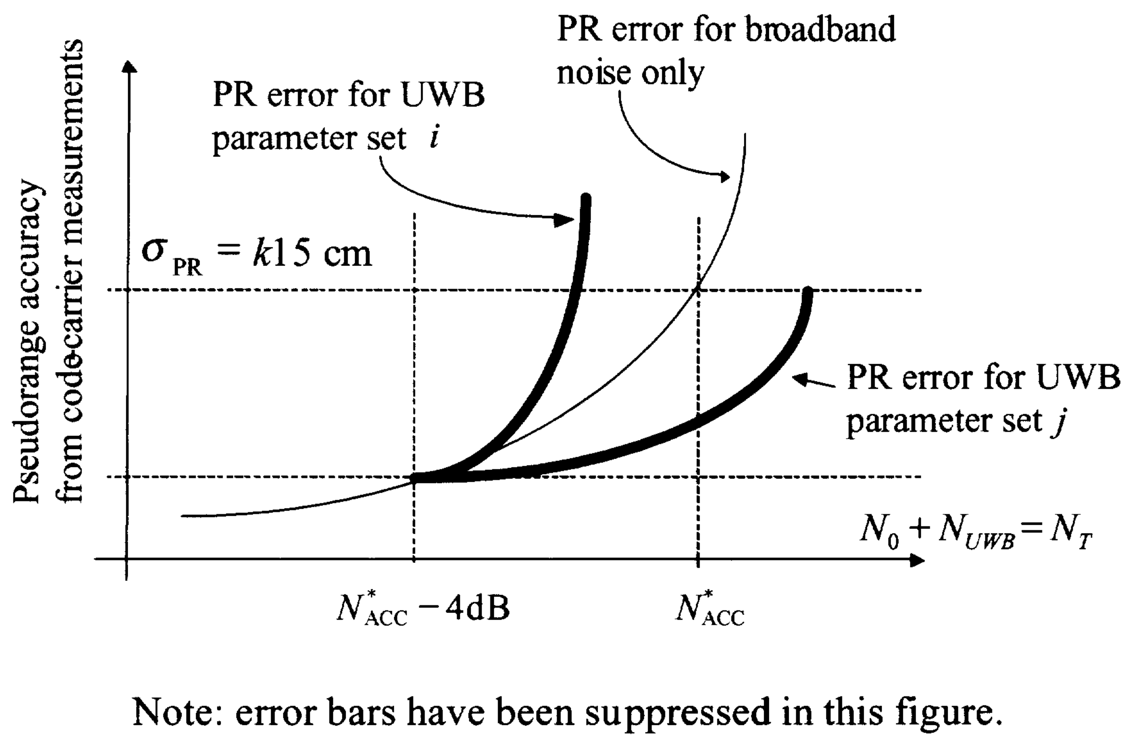

Figure 1: Pseudorange Accuracy as UWB Power is Added to Increase the Total Noise

In this example, filling the bucket with 1 liter of water represents finding the amount of broadband noise that causes the GPS pseudorange accuracy requirements to just barely be met, the 250 ml of water removed is equivalent to the 4 dB "back-off" from this amount of broadband noise power, and the ratio of the mass of the bucket after refilling with UWB liquid to that before water was removed represents the relative impact of UWB compared to broadband noise. Finding this ratio allows UWB interference to GPS to be evaluated by standard link-budget techniques that typically assume the incoming interference is white-noise-like.

Note that the amount of back-off is not critically important to this test plan, because we are comparing the UWB replacement power to the amount of broadband noise power that is removed. However, the back-off power must be chosen with some care for practical reasons. If the back-off is too large, then the test results will be dominated by the internal noise of the receiver. If the back-off is too small, then errors in measuring the UWB replacement power will be magnified.

Five potential benefits of determining the equivalence of UWB transmissions with broadband noise are:

1. The test procedure is straightforward;
2. The receivers are normalized, so that the results do not depend on how much better (or worse) the particular receiver under test is beyond the minimum operating performance standards;
3. The resulting UWB impact data can be used to evaluate specific interference scenarios (e.g., range from UWB transmitter to GPS user, antenna orientation and gain) and UWB source information to determine compatible UWB scenarios that satisfy the GPS user requirements;
4. If, during the broadband noise equivalence test, a 4 dB increase in broadband noise also corresponds to a 4 dB increase in the UWB transmitter power for the same accuracy degradation value (15 cm), then the UWB emission being tested may be classified as noise-like. In such cases a simple calculation based on broadband noise sources can determine the UWB transmission power that is tolerable; and
5. The data extracted using the single satellite testing can be readily extended for the evaluation of multiple satellite scenarios.

It should be noted that this test plan does not:

1. define or presume allowed levels of UWB transmissions; or
2. define the GPS interference scenarios of concern.

Further GPS testing beyond that being conducted at Stanford should include, at a minimum, other GPS receiver types such as fielded aviation equipment based on the TSO-C129 standard, include the aggregate effect of multiple UWB emitters, address the additive affect of other (non-UWB) systems and their allowed out-of-band emissions, and evaluate the possible non-linear effects from UWB signals with high peak powers.

These tests developed have been crafted to provide input to a separate process that considers the operational scenarios that might place UWB and GPS equipment in close proximity. UWB interference scenarios might, for example, place UWB transmitters close to GPS/cellular phone equipment required in the future to provide position reports with all E-911 calls. They may also include the use of GPS for precision approach of aircraft and for runway incursion avoidance. Each interference scenario will have a link budget that assumes that the presence of certain types of interference. The tests described here will not develop these scenarios or the associated link budgets. Rather, they will provide data on the interference effects of various combinations of UWB signal parameters, allowing scenario designers to evaluate the impact of given levels and types of UWB transmissions on real-world GPS users.

3.0 UWB Signals and Key Parameters

A UWB pulse and its frequency spectrum are shown in Figures 2 and 3, respectively. This characterization is based on a prototype UWB emitter used in initial field testing [9]. UWB is based on very short pulses and can be used for radar and communications. Its main advantages include:

- ability to mitigate multipath as a result of its short duration;
- ability to operate indoors;
- ability to operate in cities and obstructed areas;
- facilitatation of high-precision ranging and radar;
- low-power, wide-bandwidth characteristic enables low probability of interception by undesired receivers.

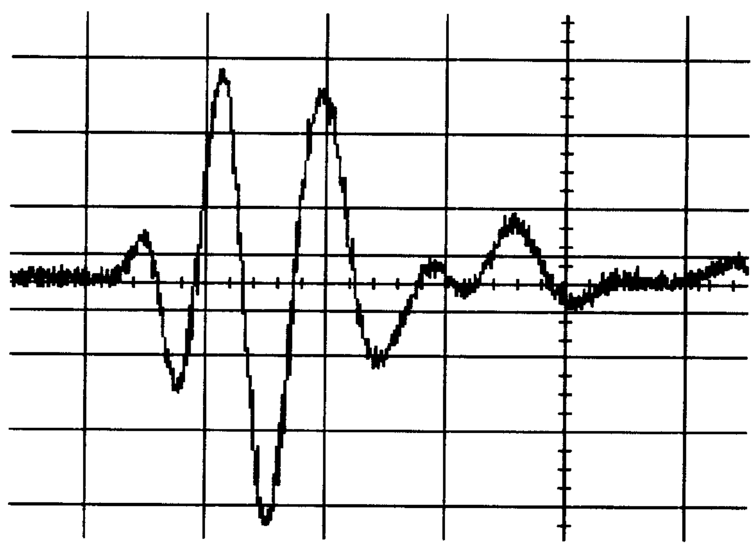

Figure 2: A Typical UWB Pulse

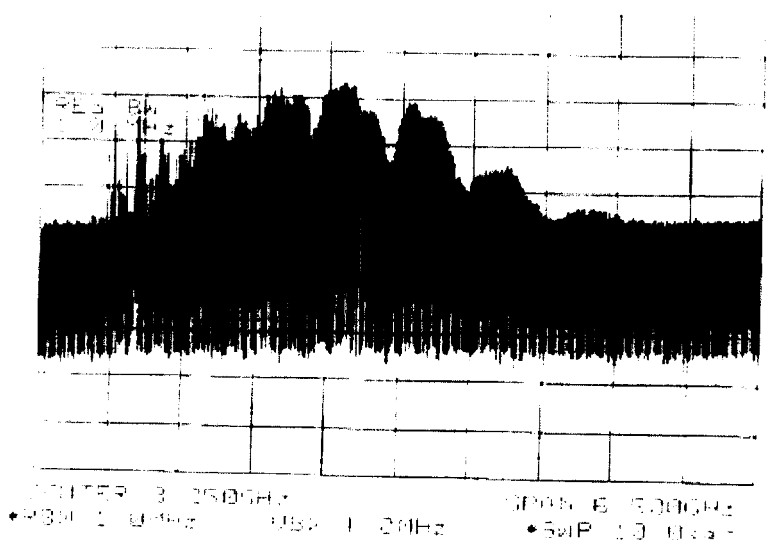

Figure 3: Spectrum of a Typical UWB Signal

UWB technology has been used in applications such as stud finding, ground penetrating radar (GPR), and military communications. Planned or proposed UWB applications include through-the-wall surveillance prior to drug raids, airport fence and airplane proximity security, aircraft navigation, communications over the "last 100 feet" from the Internet to mobile users, in-home connection from wireless microphones and cameras, connections from patients to medical monitors, car collision alerting, etc. It is projected that UWB will become such a widespread utility that there will someday be as many 10 UWB devices per person.

Though UWB could potentially have many applications, current FCC rules exclude intentional emissions from certain critical bands, including GPS. Preliminary field tests conducted at Stanford in cooperation with potential UWB manufactures demonstrated that UWB transmitter could interfere with GPS receivers [9]. However, UWB has many different parameters such as Pulse Repetition Frequency (PRF), duty cycle, burst on/off time, modulation scheme (including pulse dithering and pulse on/off keying (OOK)), filter technology, etc. The UWB pulse train and its spectrum vary accordingly, as is illustrated by the examples in Figures 4, 5, and 6 and in more detail by our test results in Section 6.0. In addition, there are many different kinds of GPS receivers, and GPS is used to serve a wide variety of applications, including safety-of-life aircraft precision approach guidance. The interference of UWB to GPS therefore depends on all of these variables. Careful testing and study are needed to evaluate potential interference to GPS and its dependence on these UWB parameters.

The goal of the testing is provide such an investigation and characterize the interference effects of UWB emissions on an aviation GPS receiver in a controlled test environment. Testing of additional receivers, primarily land, is recommended and has already been initiated. Some UWB emissions could be quite noise-like while others may have more discrete spectral lines in the vicinity of GPS. An RFI equivalence concept was developed to relate the interference impact of UWB signals on GPS over this range of UWB emissions to that of a known and well understood RFI source, i.e., broadband noise. The method chosen for this test plan is to determine the UWB interference effect for a given set of emission parameters that is equivalent to a known portion of the broadband noise input over a range of power levels around the point at which the GPS receiver achieved its required performance criterion. A sufficient level of broadband noise is input to representation the actual GPS environment.

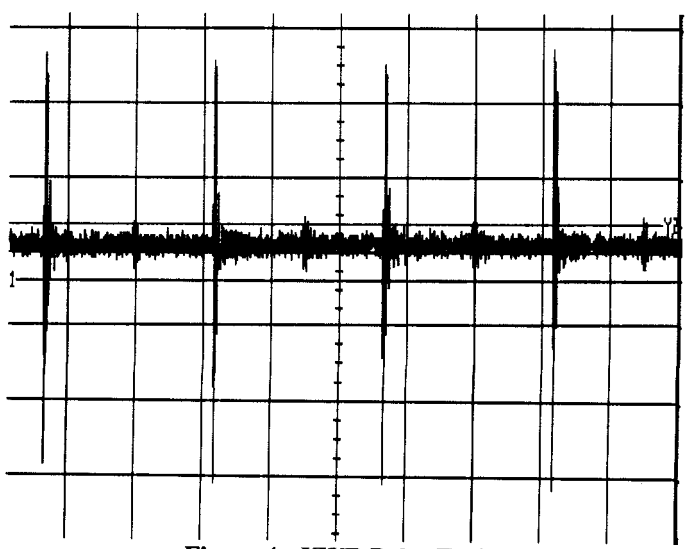

Figure 4: UWB Pulse Train

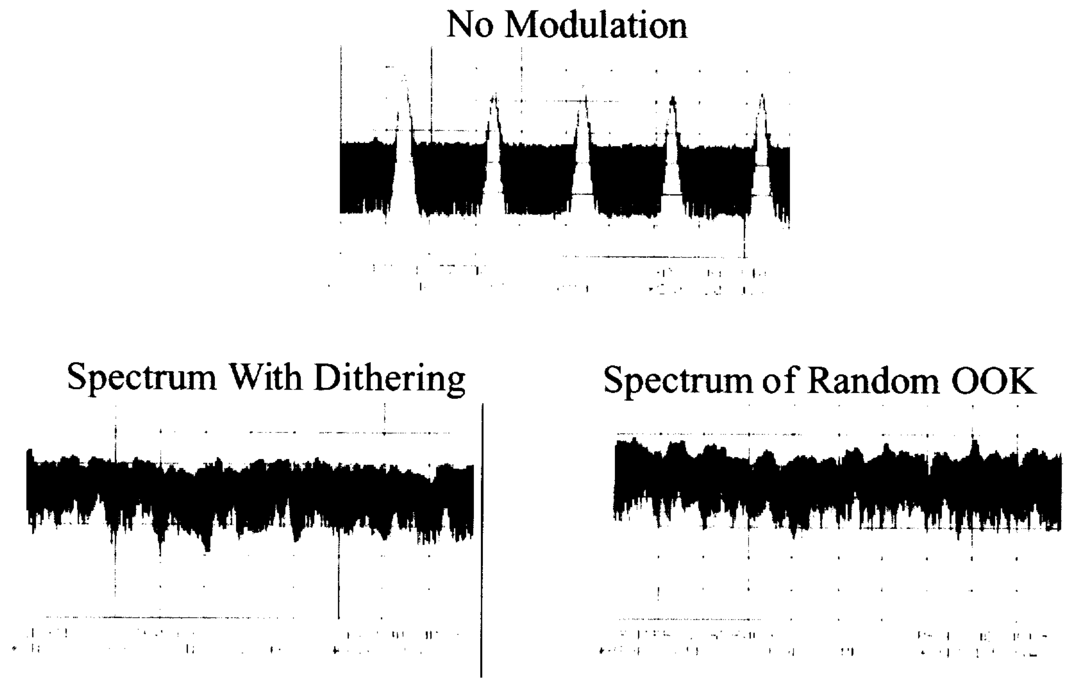

Figure 5: UWB Spectrum Examples

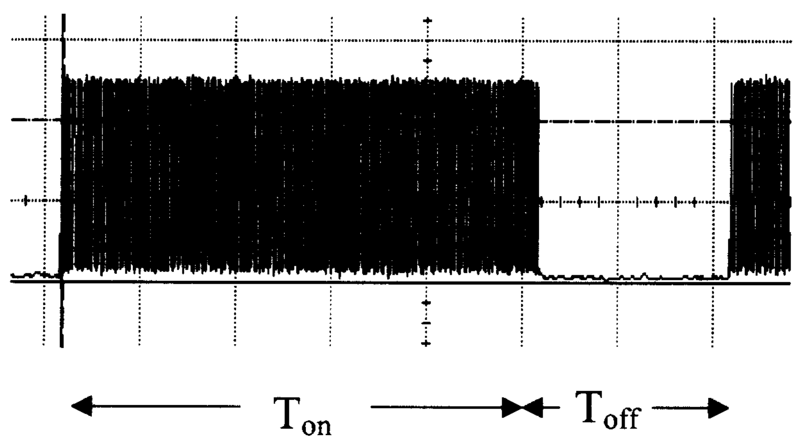

Figure 6: UWB with Burst Duty Cycle < 100%

The RFI effect of the UWB signal will be sensitive to the details of the UWB signal design. Some of these trends are depicted in Figure 7. From existing theory, the impact of a UWB waveform on GPS should be affected by the following characteristics of the waveform:

- *Pulse Repetition Frequency (PRF)*: If UWB pulses are sent at a very low rate compared to the RF front-end bandwidth of GPS receivers, then the interference impact will be smaller than that due to UWB operation at high PRFs. Most GPS receivers have front-end bandwidths between 2 and 24 MHz. If the UWB PRF is less than 2 million pulses per second (MPPS), then the pulses will still be distinct at the output of the receiver front end, and the interference will probably be relatively small. If the UWB PRF is higher than the bandwidth, then the GPS front end will smear the pulses together, forming an effectively continuous input to the GPS receiver; thus the interference effect will probably be larger.

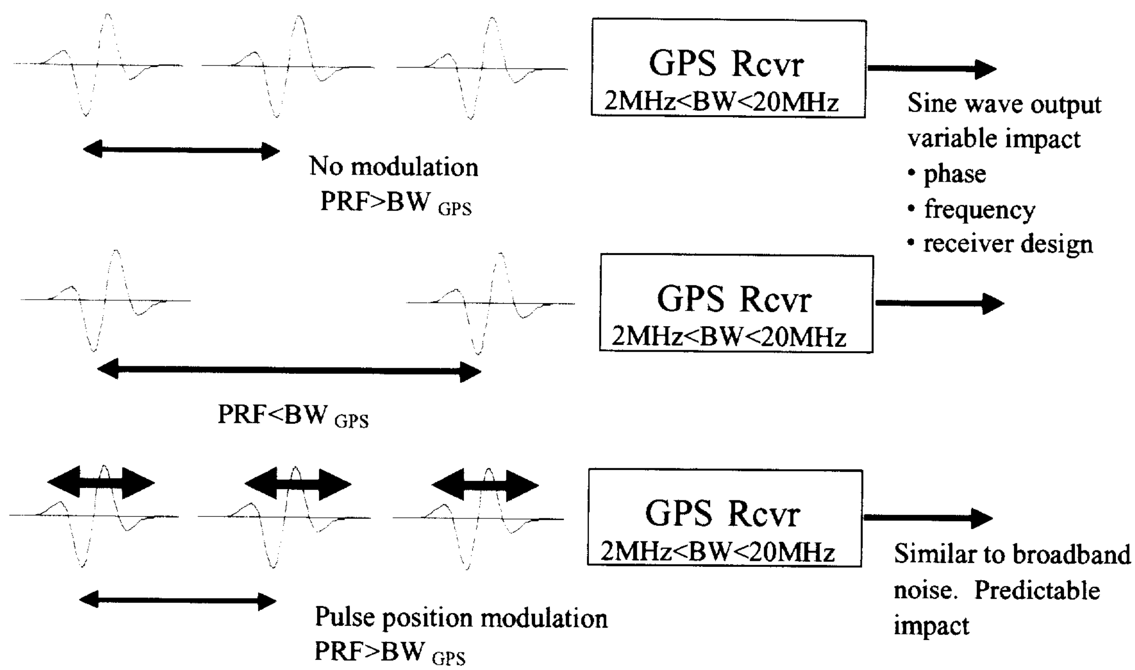

Figure 7: Sensitivity to UWB Signal Parameters

In general, GPS receivers are less sensitive to pulsed interference than they are to continuous interference.

- *No Modulation*: In this case, the UWB signal is a pulse train with a constant time between pulses. This case is shown in Figure 4, and the resulting line spectra are shown as the "no modulation" case in Figure 5. The GPS C/A-code also has line spectra. UWB interference will probably be greatest when the UWB lines fall on top of the GPS spectral lines. UWB interference should be small when the UWB lines fall between the GPS lines or are far away from the peak of the GPS spectral envelope. The locations of UWB spectral lines will change based on the UWB transmitter parameters; thus the UWB effect on GPS will vary.

- *Pulse Modulation*: If the UWB pulses are modulated randomly in pre-defined ways and with long codes, then the UWB line spectra will be reduced and may possibly disappear. If modulation is used with sequences that are continuous and have high PRFs, then the interference effect may be similar to that of broadband (white) noise of equal power.

- *Pulse Bursting*: As shown in Figure 6, UWB pulses may be transmitted in bursts with prescribed on-times and off-times. If the duty cycle (fractional on-time) of these bursts is small, then we expect that the effect of one UWB transmitter on a GPS receiver will be reduced.

- *Pulse Shaping*: The overall UWB spectrum depends on the pulse shape. It may be possible to craft the shape of UWB pulses so that the UWB spectrum avoids certain critical bands (such as the GPS L1 frequency).

All of these theoretical predictions must be quantified and validated. To this end, our test cases varied the UWB signal parameters and attempted to determine how the UWB-to-broadband noise equivalence depends on the UWB signal parameters.

4.0 Test Setup and Procedures

4.1 UWB Transmitter Prototype

The UWB transmitter prototype consists of three main components cascaded as shown in Figure 8. This is the same prototype used for the testing in [9] and also used to create the time and frequency domain figures in Section 3 of this report. The pulsar is the primary component in the system and actually generates the UWB pulse when triggered. The trigger is accomplished using an Arbitrary Waveform Generator (AWG). All modulation and duty cycle control comes via the AWG in the manner in which the pulsar is triggered. The next component is a high pass filter designed to pass frequencies above 800 MHz. The final component is an amplifier to provide gain to the signal prior to transferring power to the antenna. Interestingly the interference to GPS from this prototype observed in [9] occurred even though the GPS band, 20 MHz centered about 1575.42 MHz, is not in the specified bandwidth, 2000 MHz – 8000 MHz, of the amplifier. It is likely that UWB frequency energy within the GPS band still experienced some amount of amplification in the lower rolloff gain from this amplifier.

Pulse generator:	HL 9200
High-pass filter:	800 MHz cutoff frequency (F_C)
Amplifier:	2 – 8 GHz 20 dB gain 4 dB Noise Factor (NF)

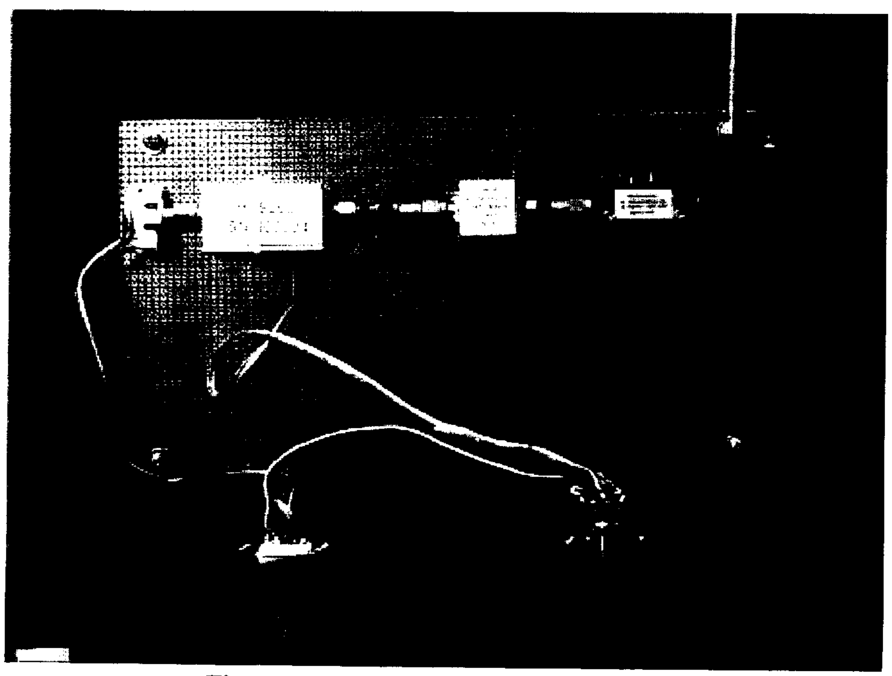

Figure 8: UWB Transmitter Prototype

In the previous testing in [9] where field testing was conducted, the UWB emitter was treated as a "black box". For the test results documented in this report, a more-controlled experiment has been conducted where all components are connected using shielded RF cables and are carefully calibrated (described in more detail in Section 4.3 and Reference [10]).

Treating the prototype as a "black box" provided the depiction of the pulse in Figure 2. However, it should be noted that this is the pulse as a result of the shaping by the components described above. For these more controlled experiment, it is possible to view the pulse at the various stages of its generation. This also allows a representation of the pulse shaping which results from the additional RF components.

An individual pulse directly from the pulsar measured in the time domain is depicted in Figure 9. Note that this picture fits the description of a "pulse" much better than that of Figure 2 as it truly looks like a single pulse. In Figure 10, a single pulse is measured at the various output stages all plotted along the same time scale. The bottom plot of Figure 10 is the pulse measurement taken at the same stage as the pulse depicted in Figure 2. Thus even in this prototype, the pulse undergoes some shaping, primarily bandlimiting, as a resulting of the additional RF components.

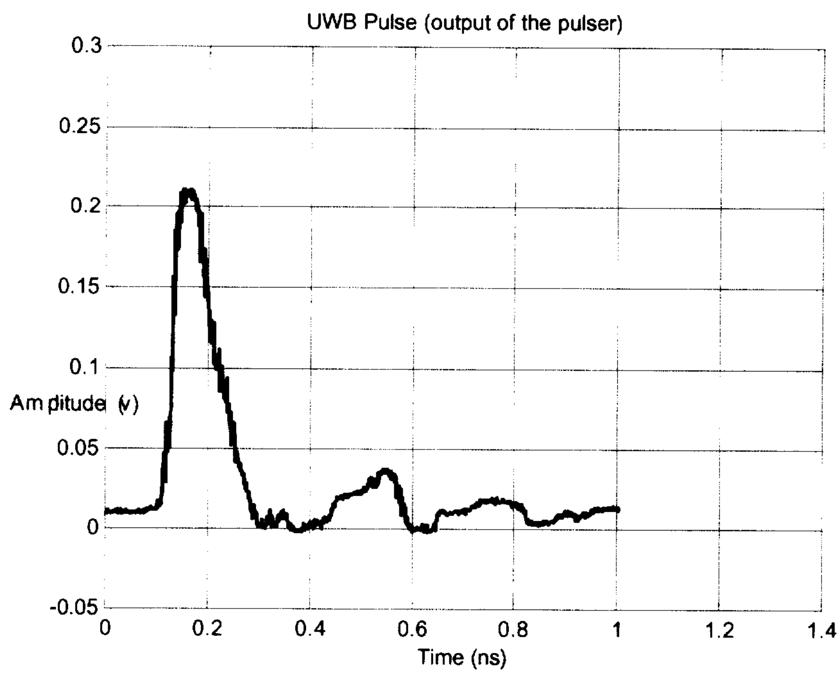

Figure 9: A Single UWB Pulse

4.2 Broadband Noise Normalization

The aviation-grade GPS receiver used in these tests is operated with a received GPS satellite signal level of −131 dBm as generated by a single-channel GPS signal simulator. Compensation is applied to adjust for room temperature, satellite simulator noise output, or the effects of a remote antenna preamplifier as needed. This level is higher then absolute specified minimum signal level in [2,3], but allows for testing in transition region of the accuracy curve which will be shown in later in this section in Figure 11. Broadband (white) random noise is added to the simulated GPS satellite signal at the receiver input. The center frequency of the broadband noise is set to the GPS L1 center frequency (1575.42 MHz). The starting value of broadband noise is the RTCA/DO-229B WAAS MOPS level required for initial satellite acquisition [3]. Once this level of broadband noise power is set, the GPS receiver is given time to acquire and track the satellite and to reach steady state. The unsmoothed pseudorange (the internal receiver carried-added-smoothing time is set to 0.5 seconds) is then recorded and an estimate derived of the one-sigma pseudorange error by computing the standard deviation of the code-minus-carrier test statistic after removing a 2^{nd}-order polynomial fit to the mean, using the algorithm defined in [4]. For each fixed broadband power level, raw code and carrier data is collected for one hour at a 2 Hz sampling rate.

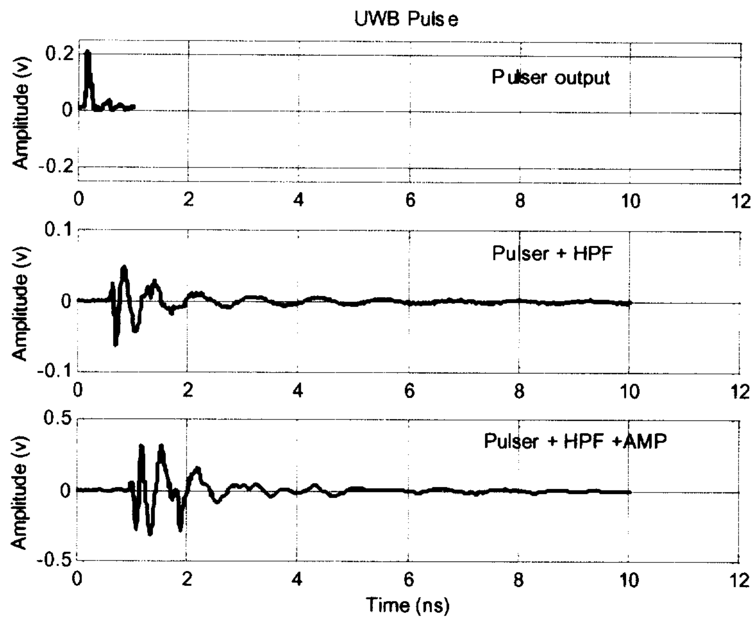

Figure 10: UWB Pulse at Various Transmitter Stages

To be conservative, 1 independent sample is assumed to occur every 4 seconds (every 8τ of internal smoothing), which gives 900 independent samples per hour. The number of samples was set so that the results allow us to distinguish the samples was set so that the results allow us to distinguish the impact of a 1 dB power difference in the pseudorange accuracy measurements with statistical precision. The normalization curve shown in Figure 11 was then obtained. This curve indicates the GPS receiver accuracy as a function of the level of broadband noise. Note that there is a difference (*k* in Figure 6) between variance measurements from raw pseudorange (PSR) and from 100-sec carrier-smoothed PSR. It is much more time-efficient to use raw PSR to increase the number of independent samples. We found that 1.4 m of raw PSR accuracy is consistently equivalent to 15 cm of carrier-smoothed PSR accuracy.

4.3 Test Setup

As shown in Figure 12, the GPS signal, broadband noise, and UWB are combined before being injected into the GPS receiver. A single-channel WelNavigate GS-100 GPS simulator is used to generate the GPS signal with satellite PRN #1. The GPS signal attenuator was set such that the GPS signal at the receiver port was −131 dBm. An HP 346B noise generator and a low-noise amplifier are used to generate broadband noise, and a manually-adjustable attenuator is

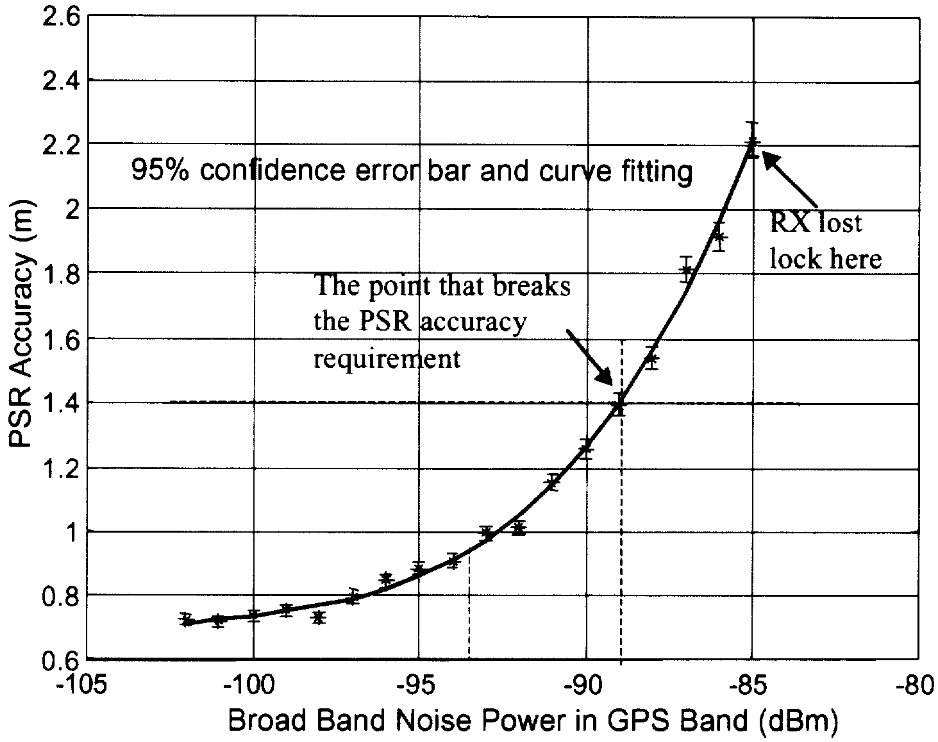

Figure 11: GPS Receiver Normalization

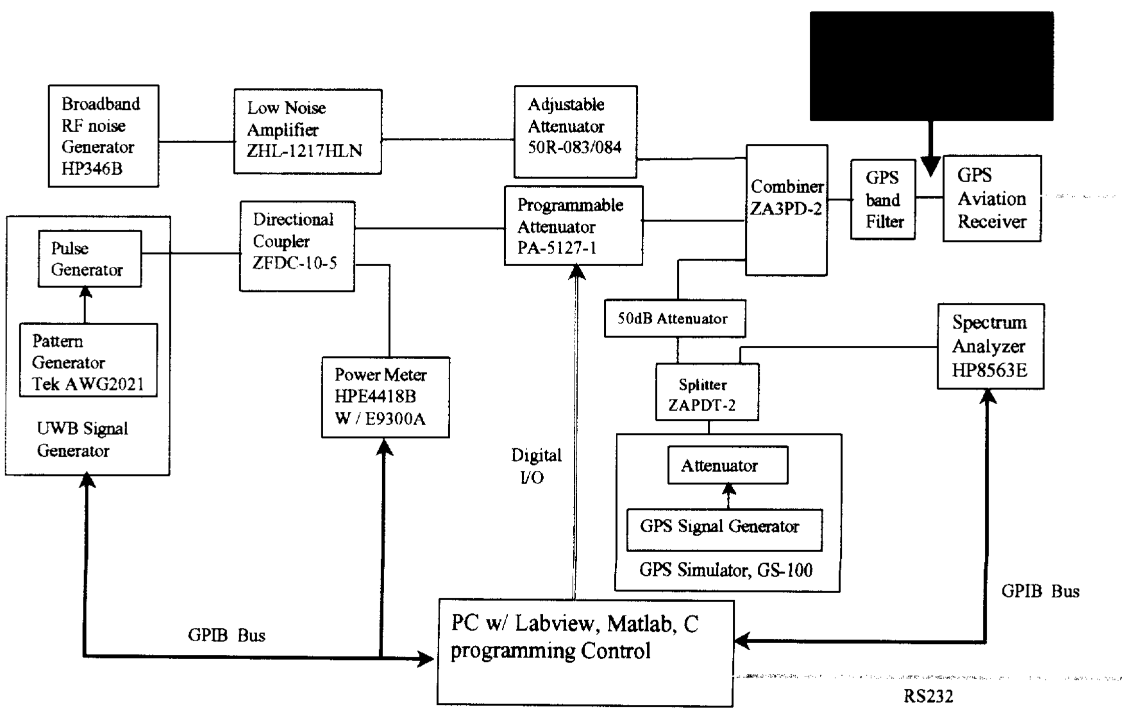

Figure 12: UWB Interference Test Setup

used to vary the RF noise power. A Tektronics AWG 2021, which triggers the UWB pulse generator, was used to trigger the pulsar to provide the desired UWB pattern. A programmable attenuator was used to sweep UWB power within the desired range. The power meter and the spectrum analyzer were used for real-time monitoring. The test has been automated using Labview and IEEE buses.

Note that a GPS L1 filter is inserted between the combiner and the GPS receiver. All power (RF and UWB) is measured in the GPS band so that they can be combined and compared later. The GPS L1 filter also controls the bandwidth of the interference and allows for a precise power measurement. The L1 filter used in our tests has the frequency characteristic shown in Figure 13.

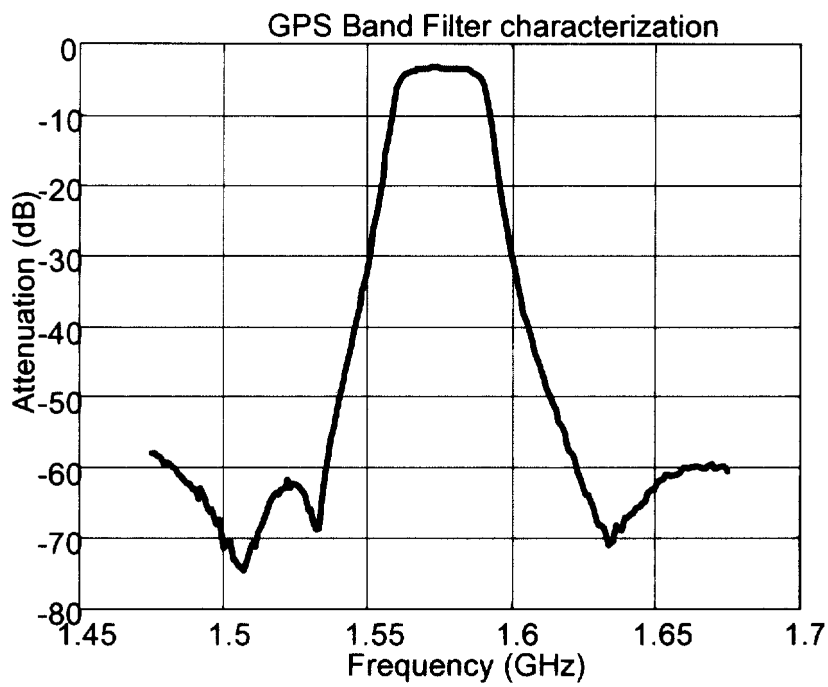

Figure 13: GPS L1 Filter Characterization

5.0 Accuracy Test Procedure for Aviation Receivers

The accuracy test procedure is described in the following two subsections. This test procedure is adapted from Section 2.5.8 of RTCA DO-229B, the *Minimum Operational Performance Standard for Avionics Using the Wide Area Augmentation System (WAAS).* As described above, it includes the following steps: calibration, normalization with white noise only, UWB interference measurements, and reporting. Sections 5.1 and 5.2 detail the broadband random noise normalization and the UWB interference measurements, respectively. Further details are given in [10].

5.1 Broadband Random Noise Normalization

1) Set up the test equipment as shown in Figure 12.

2) The GPS receiver is operated with a minimum received satellite signal level. Compensation is applied to adjust for room temperature, satellite simulator noise output, or the effects of a remote antenna preamplifier as needed. In other words, set the GPS power (C) to -131 dBm+G_{LNA} where G_{LNA} is the gain of any equipment that might nominally appear between the antenna and the receiver under test.

3) Broadband random noise is added to the simulated GPS satellite signal at the receiver input. Set the center frequency of the broadband noise to 1575.42 MHz. The starting value is the RTCA/DO-229B MOPS level for initial acquisition. Adjust the broadband noise power such that the noise power is -103.5 dBm+G_{LNA} as measured in the standard filter described earlier. The gain G_{LNA} accounts for the gain that appears between the antenna and the receiver under test. As a rough check on power levels, measure the carrier to noise density (C/N_0) as reported by the receiver. This (C/N_0) should be approximately 33 dB-Hz.

4) Let the GPS receiver track the satellite and reach steady state (for at least 10 seconds).

5) Measure the unsmoothed pseudorange and estimate the one-sigma pseudorange error by computing the standard deviation σ_r of the code-minus-carrier test statistic after removing a 2nd-order polynomial fit of the mean. Use the sample size required to achieve the confidence levels described above. Also recall that the unsmoothed pseudorange error is larger than the smoothed pseudorange error by a factor of *k*. This factor is the ratio of the noise bandwidth for the code loop to the noise bandwidth when 100 seconds of carrier smoothing is used.

6) Increase the broadband random noise power in 1 dB steps until the variance just exceeds the *k*15 cm accuracy limit. Record the noise power setting (N^*_{ACC}). Record also the C/N indicator from the GPS receiver.

5.2 Procedure for Testing Potential UWB Impact on GPS Accuracy

1) Setup the test equipment as shown in Figure 12.

2) Set the noise attenuator to 4 dB below the value obtained in Section 5.2, Step 6 (N^*_{ACC}).

3) Select one set of UWB signal parameters from the test matrix described earlier and set the UWB noise power (N_{UWB}) at least 10 dB below the broadband random noise power (N_0).

4) Let the GPS receiver track the satellite and reach steady state (for at least 10 seconds).

5) Measure the unsmoothed pseudorange and estimate the one-sigma pseudorange error by computing the standard deviation σ_r of the code-minus-carrier test statistic after removing a 2^{nd}-order polynomial fit of the mean. Use the sample size required to achieve the confidence levels described above and recall that the unsmoothed pseudorange error is larger than the smoothed pseudorange error by a factor of *k*.

6) Increase the UWB power until the *k*15 cm pseudorange variance is just exceeded. Record that power setting. Record also the C/N_0 indicator from the GPS receiver. Also find and record the accuracy when the total power (UWB plus broadband) equals the threshold power for broadband noise alone.

7) Change the UWB signal parameters to the next values in the test matrix and repeat steps 3) through 6) until all *n* combinations of UWB signal parameters are exhausted.